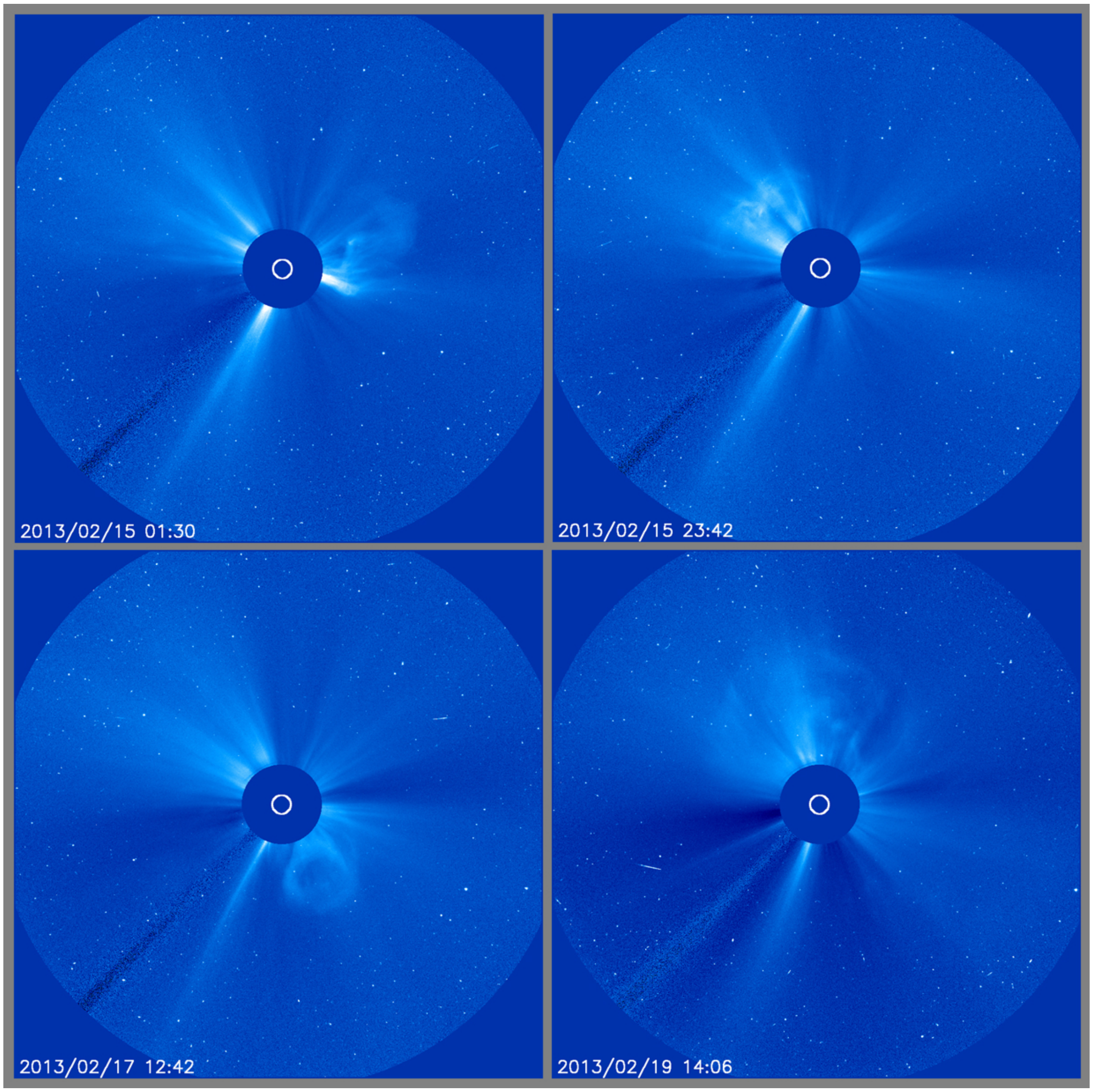
SOHO:
Toward a Complete Solar Magnetic Cycle of Measuring Space Weather



Four coronal mass ejections (CMEs) observed with the SOHO LASCO C3 coronagraph during an eight-day period in 2013 February during which there was an average of one CME per day. Will this be as active as the Sun gets in Cycle 24?

A PROPOSAL TO THE SENIOR REVIEW OF HELIOPHYSICS OPERATING MISSIONS, 2013 MARCH.

Table of Contents

Solar and Heliospheric Observatory (SOHO)

Presenters: J.B. Gurman, US Project Scientist for *SOHO*; B. Fleck (ESA; observer)

I. Executive Summary

This is the seventh Senior Review proposal from *SOHO*, a mission that has led to so many exciting discoveries and so much deeper understanding of the Sun and heliosphere, from the deep solar interior to the interstellar medium. We are not requesting an extension at the 2/3 "prime Phase E" level described as a paradigm in the call for proposals. Instead, we propose here a much lower cost mission, at the budget level of a Small Explorer mission extension, that nevertheless fulfills the requirement of the Living With a Star program's Solar Dynamics Observatory (SDO) for a white-light coronagraph to provide a Sun-earth line view of both the evolution of, and transient events in, the solar corona. That capability also provides an essential complement to planned, future missions in the proposal timeframe, as well as a unique asset for space weather modeling and prediction.

In the next section of this proposal (***Section II***), we summarize the widespread use and easy accessibility of *SOHO* data. We then discuss a few of the many insights into the physics of the Sun, heliosphere, and beyond from the analysis of *SOHO* observations published since early 2010, when our last senior review proposal was submitted. At the beginning of each highlight we note the Research Focus Areas of the 2010 Heliophysics Roadmap to which it is relevant. Finally, we describe the Prioritized Science Goals of the fiscally constrained mission – the *SOHO* "Bogart" mission – that we propose, and their relevance to the Roadmap Focus Areas and to the Heliophysics system observatory.

Section III, in turn, describes the technical and budget constraints of this new mission, and in particular addresses the issues of increased risk we must confront in order to operate what was once the great observatory of the Heliophysics System Observatory on a SMEX budget. Just as Humphrey Bogart regularly reduced cigarettes to the last nubbin, we propose to use *SOHO* capabilities throughout FY14 - FY18 to meet the critical Heliophysics system observatory need for earth-Sun line coronagraphy. For no operational or resource overhead, SOHO will continue to be able to provide total solar irradiance, low-frequency global solar oscillation, and energetic particle data from the instruments developed and operated by our European partners. For only slightly more, we can continue to provide solar wind *in situ* plasma measurements.

Appendices describe our necessarily extremely circumscribed education and pubic outreach activities (***A***), our mission archive plan (***B***), our publication record (***C***), and spacecraft and instrument status (***D***), as well as listing 2010 Heliophysics Roadmap Research Focus Areas (***E***) and acronyms (***F***).

The following individuals were among those who contributed material and/or were involved in the writing of this proposal on behalf of the *SOHO* Science Working Team: F. Auchère and P. Boumier (IAS), B. Fleck (ESA), A. Fludra (RAL), C. Fröhlich (PMOD/WRC), J.B. Gurman (GSFC), M. Hilchenbach (MPS), A. Klassen (U. Kiel), E. Quémerais (IPSI), and L. Strachan (SAO). *SOHO* is a mission of international cooperation between ESA and NASA.

II. Science and Science Implementation

IIa. Data Accessibility

Ubiquity. *SOHO* enjoys a remarkable "market share" in the worldwide solar physics community: over 4,500 papers in refereed journals since launch (not counting refereed conference proceedings, which generally duplicate journal articles), representing the work of over 3,200 individual scientists. It is not too much of an exaggeration to say that virtually every living solar or heliospheric physicist has had access to *SOHO* data.

Accessibility. We can assert that with confidence because all the *SOHO* experiments make all their data available, online, on the Web, through the *SOHO* archive, at PI sites, and via the Virtual Solar Observatory (VSO). In addition to professional access for both research and space weather prediction, amateurs routinely download LASCO FITS files and GIF images to search for new comets. As a result, 2,378 comets, well over half of all comets for which orbital elements have been determined (since 1761) were discovered with *SOHO*, over two thirds of those by amateurs accessing LASCO data via the Web. 229 comet discoveries in the last year were made with SOHO observations.

Research access. All *SOHO* instruments' scientific data are accessible through a single interface. This searches both the general *SOHO* archive at the Solar Data Analysis Center (SDAC) at Goddard, and the MDI high-rate helioseismology archive at Stanford. (MDI full-disk magnetograms obtained every 96 minutes are part of the general archive, because of their usefulness for solar activity-related research.) In both archives, and at the *SOHO* mirror site at ESAC in Spain, the holdings are identical to those used by the PI teams, and are current (i.e. to within a month or two before present, to allow time for "Level-Zero" data delivery.) A partial mirror of the *SOHO* archive is maintained at the Institut d'Astrophysique Spatiale (France) for faster access by European researchers. *SOHO* data at both the SDAC and the Stanford Helioseismology Archive were among the first data whose metadata, including browse images for EIT and MDI, became searchable via the VSO. The VSO is designed to deliver data via the original servers, so the download traffic still occurs at those sites.

Publications. The SOHO publications database can be accessed online, as can lists of papers published in refereed journals in 2010 - 2012.

IIb. Scientific Insights from SOHO, 2010 - 2012

The following, brief descriptions of scientific insights gained from *SOHO* have been gleaned from papers published in, or recently submitted to, refereed journals since the 2010 Senior Review. Scientific insights from earlier phases of the mission were covered in the proposals to the 1997, 2001, 2003, 2006, 2008, and 2010 Senior Reviews. Each insight is labeled with the Research Focus Area(s) from the 2010 Heliophysics Roadmap (see Appendix E) to which it is relevant.

Total Solar Irradiance (TSI)

TSI at the lowest activity levels (H1, H3). Using VIRGO TSI measurements as well as spatially resolved observations by MDI, Foukal, Ortiz, and Schnerr (2011) have shown that at the lowest levels of solar activity, there is a greater contribution per unit facular area than at higher activity levels. This effect may allow a "cooler Sun" during the Maunder and Spörer minima, while still accounting for sufficient activity to modulate the heliospheric magnetic field in a way that is consistent with the measurements of terrestrial ^{10}Be, which show uninterrupted modulation throughout those sunspot "grand minima."

Flares and TSI (H1, H3). Kretzschmar *et al.* (2010) analyzed 11 years of SOHO/VIRGO and GOES data to study the effects of flares on total solar irradiance. They found that the total energy radiated by flares (L_{bol}) exceeds the energy radiated in soft X-rays (L_x) by two orders of magnitude. The results have implications for our understanding of solar flares and the variability of the Sun.

Reconstruction of TSI, 1974 - 2009 (H1, H3). Ball *et al.* (2012) used groundbased and MDI magnetograms to reconstruct TSI over solar cycles 21 to 23. They found that the PMOD composite TSI (Fröhlich 2003), which is based on recalibrations of earlier measurements to reconcile them with VIRGO measurements, to be the most realistic, available record of TSI over the last three cycles. Nearly half of the (now 34-year) TSI composite is from VIRGO measurements. The TSI reconstruction model by Ball *et al.* is able to recreate TSI variations on all timescales from a day and longer over 31 years from 1978. This is strong evidence that changes in photospheric magnetic flux alone are responsible for almost all solar irradiance variations over the last three solar cycles.

Spectral Irradiance and terrestrial impacts

EUV and thermospheric variations over the solar cycle (H1, H3). Solomon *et al.* (2010) studied the extreme-ultraviolet (EUV) irradiance and thermospheric density during the recent prolonged solar minimum (2007–2009) using measurements from CELIAS/SEM and TIMED. Solar extreme-ultraviolet irradiance levels were found to be lower than they were during the previous solar minimum, and the terrestrial thermosphere was cooler and lower in density than at any time since the beginning of the space age. From a comparison of circulation model simulations with thermospheric density measurements they conclude that the primary cause of the low thermospheric density was the unusually low level of solar extreme-ultraviolet irradiance.

EUV and the ionosphere (H1, H3). Chen *et al.* (2011) studied the relationship between the solar EUV flux during the recent solar minimum, as measured by CELIAS/SEM, and the $F_{10.7}$ index, which has been routinely recorded since 1947 and is widely used in ionospheric physics as a proxy for the solar EUV flux. They found that the EUV irradiance measured by SEM was significantly lower during the recent minimum than during the previous one for the same $F_{10.7}$ level. The same was found for the critical frequency of the F_2 layer (f_0F_2) when compared to the $F_{10.7}$ index. This suggests that during the recent minimum the $F_{10.7}$ index was not a good proxy for the solar EUV flux, although it was adequate during previous minima. Solar irradiance models and ionospheric models will need to take this into account for solar cycle investigations.

Heliosesimology and the Solar Cycle

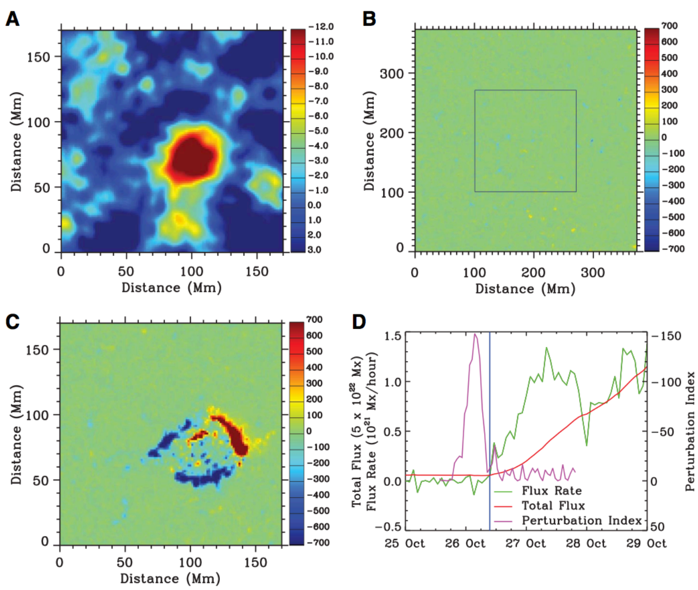


Figure 1. (A) Sound travel time pertrubation (in s) at the same time as the photospheric magnetic field appeared as in (B). (C) The photospheric magnetic field 24 hours later. (D) Total, unsigned magnetic flux (red) and flux rate (green) of NOAA active region 10488. The blue line marks the time when the first active region flux began to emerge, some 6 hours after the conditions in (A) and (B).

Detection of emerging sunspot regions below the visible surface (H1, J1, J2, J3). Ilonidis, Zhao, and Kosovichev (2011) have used a time-distance helioseismology analysis, including a novel phase-speed filter, to analyze MDI "time-distance" helioseismology observations. They show that acoustic travel-time anomalies of up to 16 seconds occur as deep as 65 Mm below sites where active regions with sunspots are about to emerge, up to two days before the spot emergence. Their methods have also been applied successfully to measurements with the HMI instrument on SDO.

Meridional circulation and the solar cycle (F4, H1, J2). The late onset of the new solar cycle and the unusually deep minimum between cycles 23 and 24 took many by surprise, which suggests that there is a fundamental lack in our understanding of the origin of the solar activity cycle. The Sun's meridional circulation, a massive flow pattern within the Sun that transports hot plasma near the surface from the solar equator to the poles and back to the equator in the deeper layers of the convection zone, is believed to play a key role in determining the strength of the Sun's polar magnetic field, which in turn determines the strength of the sunspot cycles. One class of dynamo models predicts that a stronger meridional flow produces weaker polar fields, whereas another class of models predicts stronger polar fields (and a shorter sunspot cycle) for the same flow. Analyzing more than 60,000 full disk MDI magnetograms between 1996 May and 2009 June, Hathaway and Rightmire (2010) measured the latitudinal profile of this flow and its variations over a solar cycle by tracking the motions of small-scale magnetic flux concentrations, which are carried away by the meridional flow like leaves on a river. They found an average flow that is poleward at all latitudes up to 75°. They also determined that the flow was faster at solar minimum than at maximum, and substantially faster on the approach to the current minimum than it was at the same phase of the previous solar minimum. This finding poses new constraints on solar dynamo models and may help to explain why the last solar minimum was so peculiar.

Following up on this work, Hathaway and Rightmire (2011) studied the variations of the axisymmetric transport of magnetic elements on the Sun from 1996 to 2010 using MDI magnetograms. They found that *(i)* the differential rotation is weaker at maximum than at minimum, *(ii)* the meridional flow is faster at minimum and slower at maximum, *(iii)* the average latitudinal profile is largely a simple sinusoid that extends to the poles and peaks at about 35° latitude, and *(iv)* there are polar countercells (equatorward flow at high latitudes) in the south from 1996 to 2000 and in the north from 2002 to 2010.

Meridional circulation: return flow (H1, J2). Most recently, Hathaway (2012) used MDI data to study the depth dependence of the Sun's meridional flow, with supergranular cells as markers. He found evidence that the poleward meridional flow returns equatorward at depths > 50 Mm, just below the base of the surface shear layer. He also found evidence of a substantial equatorward flow (4.6 ± 0.4 m/s) at a depth of ~70 Mm. If confirmed, this would present the first positive detection of the Sun's meridional return flow in the solar interior.

Magnetic Fields and the Solar Cycle

Magnetic properties of bipolar regions: implications for sunspot origins (F4, H1, J2). Stenflo and Kosovichev (2012) studied the properties of bipolar active regions on the Sun using the complete set of 73,838 full-disk synoptic magnetograms obtained by MDI during 1995 - 2011. They identified over 160,000 bipolar active regions that span a range of scale sizes of nearly four orders of magnitude and performed a statistical analysis of their polarity orientations, including their tilt-angle distributions and their violations of Hale's polarity law. They show explicit examples, from different phases of the solar cycle, where well-defined, medium-sized, bipolar regions with opposite polarity orientations occur side by side in the same latitude zone in the same magnetogram. Such oppositely oriented large bipolar regions cannot be part of the same toroidal flux system, but different flux systems must coexist at any given time in the same latitude zones. These examples are incompatible with the paradigm of coherent, subsurface toroidal flux ropes as the source of sunspots, and instead show that fluctuations must play a major role at all scales for the turbulent dynamo.

The solar atmosphere

Distribution of transition region intensities (H1, J1). Using CDS O V 629.7 Å and MDI photospheric magnetic measurements, Fludra and Warren (2010) have shown that only about 25% of the pixels in areas surrounding active regions have transition region intensities at a basal level derived from the underlying magnetic flux and the inferred loop length. Instead, the majority of active region pixels at a resolution of a few arc seconds have intensities 2 - 3 times higher than the simple basal flux model would predict.

Propagating disturbances in a polar coronal hole (H1, J3). Gupta *et al.* (2012) have "observed the archive," using SUMER observations of of the N IV 765Å and Ne VIII 770 Å lines originally obtained for a study of polar jets to search for propagating disturbances in a polar coronal hole. They found periodic power in Ne VIII around 14.5 minutes in both intensity (with 5 - 10% amplitude) and Doppler velocity (3 - 6 km s^{-1} amplitude), but none in N IV. Since blueshifts were in phase with intensity variations, they interpret these observations as evidence for slow-mode acoustic waves with projected propagation speeds of 60 km s^{-1}.

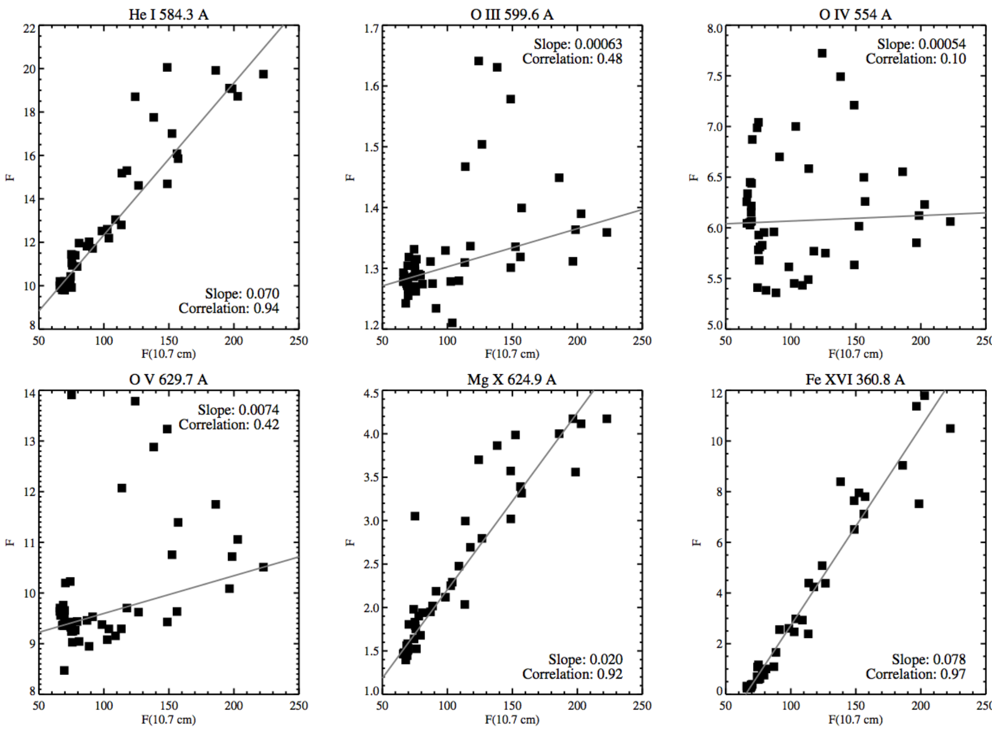


Figure 2. Variation in full-disk integrated flux of six EUV lines as a function of 10.7 cm radio flux during 1998 - 2010.

Solar cycle variation in EUV line emission (H1, J1). In a good example of the kind of study enabled by *SOHO*'s remarkably long lifetime, Del Zanna and Andretta (2011) used 13 years of CDS full-disk images in EUV spectral lines formed over a wide variety of temperatures to examine the variation of solar spectral line irradiance over more than a solar activity cycle. After careful calibration, the results show good agreement with TIMED/SEE and EVE prototype rocket measurements. While the output in most transition region lines other than those of He I and He II are found to vary little over the survey period, significant variation, well correlated with $F_{10.7}$ emission (see Figure 2), is found for the Mg X 624.9 Å (formed at 10^6 K) and Fe XVI 360.8 Å (formed at 2.5 x 10^6 K) lines.

The Corona

SEPs from a broad CME shock (F2, J2, J3). Rouillard *et al.* (2012), studying a wide, fast CME in detail using *SOHO*, WIND, and STEREO, determined that difference in the times when SEPs were detected by STEREO Ahead IMPACT and *SOHO* ERNE – the two spacecraft were on field lines separated by some 90° at the Sun – corresponded to the time it took the CME to expand laterally across that range and run into a streamer.

Flux tube expansion (F2, J3). Using UVCS O VI measurements at 2.3 R_{Sun}, Strachan *et al.* (2012) have mapped electron densities and outflow velocities (using Doppler dimming) to establish solar wind flux tube expansion factors and mass fluxes in the corona. They find that during most of the solar minimum period, the solar wind in the polar coronal holes expands superradially with areal expansion factors > 1, but those values shrink to near unity as the polar holes recede during the rising phase of the cycle. Dynamic flux tubes expansion factors $f_{exp} = (NV)_{base} / [(NV)_s{}^*R_s{}^2]$, where R_s is the source surface (in this case, the UVCS measurement) height, vary from near 1 at the center of the polar holes to ~ 4 near the hole/streamer boundary; the larger expansion factors at lower latitudes may explain the decrease in solar wind speed with latitude. Finally, the outflow speeds at all latitudes at 2.3 R_{Sun} are below 200 km/s, which suggests that there is additional acceleration in the extended corona before the solar wind reaches it terminal speeds in both coronal holes and streamers.

CME properties (H1, J2, J3). Vourlidas *et al.* (2010) present a comprehensive analysis of CME mass and energy properties over a full solar cycle. Their analysis suggests the existence of two event classes: "normal" CMEs reaching constant mass for > 10R_{Sun} and "pseudo" CMEs which disappear in the C3 field of view. They also find a sudden reduction in the CME mass in mid-2003, which may be related to a change in the electron content of the large-scale corona at that time, and they notice the presence of a 6-month periodicity in the ejected mass from 2003 onward.

The Heliosphere

Energetic neutral atoms (F2, F3, J1). Czechowski *et al.* (2012) have used CELIAS HSTOF measurements of energetic (58 - 88 keV) neutral hydrogen and (28 - 58 kEV/n) He, possible only during the very quiet periods, to infer that the energetic neutral atom (ENA) flux from the flanks of the heliosheath is similar to that from the forward (upwind) sector. These results imply a thickness for the forward sector of ~ 20 - 30 AU, similar to results from IBEX and Voyager I.

Space Weather

CMEs and SEPs (F2, J2). Using LASCO CME data from 1997 to 2006, Park *et al.* (2012) studied the probability of occurrence of solar proton events and the dependence of their peak fluxes on CME parameters. They found a strong dependence on CME speed and angular width.

The following synopses of works that assess the state of the art in space weather prediction underline the centrality of the LASCO CME database, now extending more than 1.5 solar activity cycles, in improving our ability to detect, measure, and predict the effects of space weather events.

Predicting ICME geoeffectivness (J2). Richardson and Caine (2011), using their own catalog of over 300 interplanetary CMEs (ICMEs) during the years 1996 - 2009 and based on LASCO as well as in situ measurements, examined the best way to predict geoeffectiveness. They concluded that the speed of an ICME approaching the earth, as measured by coronagraphs or heliospheric images on spacecraft "well separated form the earth," is likely to be able to estimate the geoffectiveness with a longer lead time than an upstream, in situ monitor in the solar wind.

Predicting the arrival time of large geomagnetic storms (J2). Taktakischvili *et al.* (2011) examined the success of the WSA-ENLIL model used at the Goddard Community Coordinated Modeling Center (CCMC) in predicting arrival times at earth of 36 storms with $K_p \geq 8$. Using the LASCO catalog to identify all but twelve of the events, they found a mean error of ±11.2 hours in arrival time. Interestingly, the mean arrival time error in predictions using the empirical model of Gopalswamy *et al.* (2005) is only ±8 hours. The NOAA SWPC group, who use a different variant of the ENLIL model, have achieved an rms absolute arrival time uncertainty of ±7.3 hours (Biesecker, private communication).

References

Ball, W.T., Unruh, Y.C., Krivova, N.A., Solanki, S., Wenzler, T., Mortlock, D. J., and Jaffe, A. H. 2012, A&A, 541, doi: 10.1051/0004-6361/201118702

Chen, Y., Liu, L., and Wan, W. 2011, JGRA, 116, A04304, doi: 10.1029/2010JA016301

Czechowski, A., Hilchenbachm M., and Hsieh, K.C. 2012, A&A, 541, 14, doi: 10.1051/0004-6361/201118570

Del Zanna, G. and Andretta, V. 2011, A&A, 528, A139, doi: 10.1051/0004-6361/201016106

Fludra, A. and Warren, H. 2010, A&A, 523, A47, doi: 10.1051/0004-6361/2010014261

Foukal, P., Ortiz, A., and Schnerr, R. 2011, ApJ, 733, L38, doi: 10.1088/2041-8205/733/2/L38

Fröhlich, C. 2003, Meteorologia, 40, 60

Gopalswamy, N., Lara, A., Manoharan, P.K., and Howard, R. 2005, Adv. Space Res., 36, 2289

Gupta, G.R., Teriaca, L., Marsch, E., Solanki, S.K., and Banerjee, D. 2012, &A, 546, A93, doi: 10.1051-6361/201219795

Hathaway, D.H. 2012, ApJ, 760, 84, doi: 10.1088/0004-637X/760/1/84

Hathaway, D.H. and Rightmire, L. 2010, Science, 327, 1350, doi: 10.1126/science.118990

Hathaway, D.H. and Rightmire, L. 2011, ApJ, 729, 80, doi: 10.1088/0004-637X/729/2/80

Ilonidis, S., Zhao, J., and Kosovichev, A. 2011, Science, 333, 993, doi: 10.1126/science.1206253

Kretzschmar, M., de Wit, T.D., Schmutz, W., Meaoui, S., Hochedez, J.-F., and Dewitte, S. 2010, Nature Physics, 6, 690, doi: 10.1038/nphys1741

Park, J., Moon, Y.-J., and Gopalswamy, N. 2012, JGRA, 117, A08108; doi: 10.1029/2011JA017477

Richardson, I.G. and Caine, H.V. 2011, Space Weather, 9, S07005, doi: 10.1029/2011SW000670

Rouillard A.P. et al. 2012, ApJ, 752, 44, doi: 10.1088/0004-637X/752/1/44

Stenflo, J.O. and Kosovichev, A.G. 2012, ApJ, 745, 129, doi: 10.1088/0004-637X/745/2/129

Strachan, L.Panasyuk, A.V., Kohl, J.L., and Lamy, P. 2012, ApJ, 745, 51, doi: 10.1088/0004-637X/745/1/51

Taktakischvili, A., Pulkinnen, A., MacNeice, P.M., Kuznetsova, M., Hesse, M., and Odstrcil, D. 2011, Space Weather, 9, S06002, doi: 10.1029/2010SW000642

Vourlidas, A., Howard, R.A., Esfandiari, E., Patsourakos, S., Yashiro, S., and Michalek, G. 2010, ApJ, 722, 1522, doi: 10.1088/0004-637X/722/2/1522

Xie, H., L. Ofman, and G. Lawrence 2004, JGR, 109, A03109, doi:10.1029 / 2003JA010226

IIc. Prioritized Science Goals, FY14 - FY18

Goal 1: Provide Sun-earth line, visible light coronagraphy for the Heliophysics System Observatory (H1, J2, J3)

With the other US PI-led *SOHO* instruments MDI and UVCS no longer operational, the principal NASA interest in continuing *SOHO* mission operations through at least FY2018 is the need for visible light coronagraph imagery of sufficient quality and frequency to enable both original research on solar and heliospheric activity and maintaining the reliability of space weather prediction.

In combination with SDO's AIA extreme ultraviolet telescopes, LASCO provides information on whether a halo coronal mass ejection is headed toward the earth, or in the opposite direction. STEREO can aid in improving the accuracy of that determination, but STEREO depends primarily on antenna operators who perform the function on a goodwill basis for less than complete coverage of the "space weather beacon mode" – which returns spatially binned, extremely lossily compressed EUV images that are not always conclusive in detecting CME initiations. (Full resolution, much less lossily compressed data from STEREO arrive two to three days later via the DSN – too late for space weather forecasting.) In contrast, *SOHO* is fully supported by the DSN, with a target gap of no more than eight hours between realtime contacts, in order to provide sufficient realtime LASCO C3 imagery to allow the determination of plane of the sky speeds for even the fastest (> 2500 km/s) CMEs.

Over the last several years, both the NOAA Space Weather Prediction Center (SWPC) and NASA Goddard's Community Coordinated Modeling Center (CCMC) have implemented (slightly different) versions of the ENLIL time-dependent, three-dimensional, magnetohydrodynamic model of the heliosphere (Xie *et al.* 2004) as regular forecasting tools. In both cases, initial speeds, acceleration, and source active region locations of CMEs are the initial boundary conditions for modeling CME arrival times at 1 AU. Both SWPC and the CCMC have initiated Web services with continually updated model runs, and the nowcast information is even available in mobile apps. While SWPC is the nation's operational space weather forecast provider, both groups have made major strides in enabling accurate (6 - 12 hours rms uncertainties for arrival times at 1 AU) space weather situational awareness – and in both cases, the unique and as yet irreplaceable input is *SOHO* LASCO visible-light coronagraphy.

Without LASCO near-realtime imagery, we would find ourselves back where we were prior to the launch of *SOHO* in 1995: with ICME propagation as a research area short on definitive data, but not a predictive science. Since we have no spacecraft upwind of the earth by more than 0.01 AU, we would find ourselves, at a time when electric power distribution is unregulated but geographically interdependent, with no warning of impending, potentially geoeffective events in advance of the passage of the interplanetary CME past L1 sentinels such as ACE and WIND. That this is recognized as a national interest of the United States may be seen from the following letter recently sent by NOAA National Weather Service management to the NASA Associate Administrator for the Science Mission Directorate.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
1325 East-West Highway
Silver Spring, Maryland 20910-3283
THE DIRECTOR

DEC 18 2012

Dr. John M. Grunsfeld
Associate Administrator
for the Science Mission Directorate
National Aeronautics and Space Administration
300 E Street, S.W.
Washington, DC 20546

Dear Dr. Grunsfeld:

I am writing you to request dedicated support for the operation of the ground systems that provide SOHO/LASCO and STEREO/SECCHI coronagraph data to the National Oceanic and Atmospheric Administration (NOAA).

The threat an extreme geomagnetic storm poses to the Nation's critical infrastructure is well-recognized throughout our community and throughout the highest levels of government, including the Executive Office of the President. One key to protecting the Nation's critical infrastructure is the accurate prediction of geomagnetic storms. To better warn the Nation of impending geomagnetic storms, and as a result of collaborative efforts between NSF, NASA, and NOAA, the WSA-Enlil model was transitioned into operations at NOAA in 2012. Coronagraph observations provide the optimal input parameters to properly initialize the WSA-Enlil model with the solar events that cause geomagnetic storms. Today, the only reliable source of coronagraph data comes from the NASA SOHO/LASCO and STEREO/SECCHI research missions. It is of vital importance to NOAA that coronagraph observations continue to be available to support this critical function for the Nation.

NOAA has specific operational requirements for the SOHO/LASCO and STEREO/SECCHI instrument data. Our base requirements are that they be available at an approximate 15 minute cadence, with gaps between real-time contacts of no greater than 8 hours.

NOAA recognizes the value coronagraph data have to its mission and we are actively working to secure funding for an operational replacement. In the meantime, NOAA is requesting NASA's dedicated support to ensure the availability of the existing coronagraph data for our operational use and ensure that the Nation's interests are adequately protected.

I am confident that we can help keep the momentum of our agencies' partnership moving forward. If you have any questions please do not hesitate to have your staff contact Mr. Brent Gordon, Space Weather Services Branch Chief, at (303) 497-4468 or brent.gordon@noaa.gov.

Respectfully,

Laura K Furgione

Laura K. Furgione
Acting Director

THE ASSISTANT ADMINISTRATOR
FOR WEATHER SERVICES

Printed on Recycled Paper

Toward the end of the FY2014 - 2018 proposal period, we will at long last be sending the first of two probes to the inner heliosphere to expand the work of the Helios probes launched in the 1970's: ESA's Solar Orbiter, to be followed sometime later by NASA's Solar Probe Plus. LASCO and SDO imagery will provide unique and essential context information for any heliospheric events on the earthward side of the Sun for at least the first three years of Orbiter's transfer phase, while both STEREO spacecraft are on the far side of the Sun.

Goal 2: Continue to enable long-baseline and space weather-relevant science with European-led investigations (F2, F3, H1, H3, J2, J3)

Funding for CDS operations will extend only to 2013 September, and the SUMER PI has announced plans to end science operations after a single campaign of co-observing with IRIS some time in the summer of this year. Since MDI and UVCS have already ceased science operations, that will leave – in addition to LASCO – CELIAS (solar wind plasma and composition), EIT (EUV imaging), VIRGO (total and spectral solar irradiance and low-l helioseismology), GOLF (low-l helioseismology), SWAN (interstellar wind and farside coronal Ly α imaging), ERNE, and COSTEP (both energetic particle investigations) – all led by European PIs.

CELIAS will be considered in the next subsection (Goal 3), and EIT, which shares CPU and memory with LASCO, is used for only a few images per day, to track throughput changes without interrupting the LASCO observing program. We describe in the following paragraphs some of the science that can be achieved in the next five years by the other, European-led investigations on *SOHO*.

2.1 TSI variations and solar "forcing" of terrestrial climate. A long-term, accurate, absolutely calibrated record of both total solar irradiance (TSI) and spectral irradiance is essential for understanding the degree to which solar forcing affects climate on earth. Interpretation of the TSI and spectral irradiance record, whether as a steady cycle with no underlying secular change or as showing an increasing trend, has broad social and political impacts as governments make decisions on their responses (if any) to global warming. The TSI record from the SOHO VIRGO radiometers now extends over 17 years. Significant differences in the designs of the different VIRGO sensors have made it possible to determine and eliminate instrumental aging from the record of VIRGO, and the same methods have been applied to earlier TSI measurements to compile a TSI composite that now spans over 34 years. VIRGO measurements showed that the recent peculiar minimum between cycles 23 and 24 was 0.20 Wm^{-2} lower than during the previous minimum in 1996, a decrease of 24% of the typical cycle amplitude of 0.87 Wm^{-2}. This result has been confirmed by ACRIM and SORCE and constitutes the first directly observed, secular change in the Sun's total energy output. Other important measurements are obtained with the VIRGO sunphotometers, which measure the spectral irradiance at 402, 500 and 862 nm with a bandwidth of 5 nm. Preliminary analysis of these time series shows that all three are positively correlated with the solar cycle, in contradiction to recent findings based on SORCE/SIM data. Continued operation of the VIRGO instruments will allow redundant, overlapping measurements of one of the most fundamental solar quantities with current and new radiometers, which is critically important for extending the 34-year record of TSI measurements. It will allow us to determine in what ways solar output variations during cycle 24 are similar to, or different from, those of previous cycles.

2.2 Solar cycle changes in the solar interior. Analysis of low-degree mode frequencies obtained with GOLF shows a correlation of frequency changes with the solar cycle. Interestingly, the l=2 modes, which are more sensitive to the polar regions of the Sun, show variations in sync with the sunspot cycle, whereas the l=1 modes, which are more sensitive around the equator, show a considerable delay in the sunspot minimum. The extension of *SOHO* will allow GOLF to follow during the entire cycle how the various families of modes evolve relatively to each other. A recently discovered quasi-biennial periodicity in the frequency shifts measured by GOLF raises the question of the existence of a dynamo with a two year periodicity. These new findings have to be confirmed and the location of such a dynamo (if it indeed exists) determined. Thanks to a new calibration procedure, the GOLF team is now able to build a surface magnetic activity proxy based on the modulation produced in the light curve by the surface magnetic structures. Synergies with SDO will help us develop a more complete picture of solar cycle changes inside the Sun.

2.2 Solar core and global structure. GOLF has seen tantalizing evidence for the existence of *g*-modes (modes for which buoyancy is the restoring force), which probe the solar core. The analysis performed during the last two years favors a core rotation rate 5 to 8 times higher than in the radiative zone. Is this rotation rate a relic of the young Sun? What is the direction of the core rotation axis? If confirmed with new data, this could lead to new insight into the formation of the solar system. To make progress on the *g*-mode detection, the solar background noise caused by convective motions and active regions will have to be reduced. Longer time series help in that respect, but not by much, given the fact that we already have more than 17 years of data. Much more promising is the fact that SDO/HMI data can be combined with GOLF data. SDO/HMI is observing at a different height in the solar atmosphere in which the convective background is different. This should lead to a significant improvement in the identification of low-degree *p*- and *g*-modes. With the extension of the mission we will be able to build a homogeneous time-series of global solar oscillations of exceptional quality and continuity, covering two solar magnetic (22-year) cycles, which will probably not be repeated, let alone surpassed, for many decades (if ever).

2.2 UV irradiance predictions. SWAN full-sky images are used routinely to monitor the spatial and temporal variations of the solar Lyman-α flux, in particular also of the flux distribution emitted from the far side of the Sun. These measurements are used for improved models for forecasting XUV/EUV/UV irradiance on a time scale of 7–20 days. This provides an important resource for forecasts of the thermospheric neutral density and the degree of ionization of the terrestrial ionosphere as well as for other planets and the interplanetary medium. Using these results in Earth atmospheric models can lead to substantial improvements of satellite drag and communications forecasts. The predicted values are available routinely at the SWAN Website, under "Solar Indices Forecast."

2.3 Hydrogen sources in the inner heliosphere. The SWAN team is planning to perform cross-calibration observations of the interplanetary medium with the PHEBUS spectrometer on-board Bepi-Colombo (same PI). Similar observations were successfully performed with the UVVS-MASCS instrument on-board Messenger. Such coordinated observations will allow to not only cross-calibrate the two instruments but also to determine the column density of hydrogen atoms between the two spacecraft. With such observations between SOHO and Bepi-Colombo, we will be able to scan the hydrogen distribution within the orbit of SOHO and look for inner heliospheric sources of hydrogen like outgassing interplanetary dust grains. Bepi-Colombo is scheduled for launch in 2015. There will be opportunities of coordinated observations in 2015 and 2016.

2.4 Microscopic solar source regions of the solar wind. The microscopic solar source regions of the solar wind are still not known. Recent observations with high-resolution remote-sensing instrumentation on Hinode and SDO have revealed remarkable small-scale and often short-time phenomena which are believed to feed into the solar wind. Typical times scales range from hours to days. This is faster than the time scales commonly used for in-situ composition studies in the solar wind. Small-scale or fast variations in the solar wind have only very rarely been studied in the past mainly because of instrumental limitations. We propose to measure such short-term composition fluctuations in the solar wind with SOHO/CELIAS/MTOF and relate them to the solar surface to determine the microscopic origin of individual solar wind parcels. Thus SOHO will provide preparatory work for linking solar source regions to in-situ measurements, which is a key objective of the upcoming Solar Orbiter mission. And near real-time CELIAS/MTOF Proton Monitor data will remain critically important during energetic particle events. The only other available real-time data are from ACE, which are seriously degraded during intense energetic particle events, and from the STEREO spacecraft, which are now far from the Earth-Sun line.

2.5 Multi spacecraft observations of near relativistic electrons. About 15 near relativistic electron events with a longitudinal spread of more than 90° have been recorded by the COSTEP/EPHIN and SEPT instruments aboard SOHO and STEREO. Surprisingly, there are events in which the longitudinal spread of energetic particles is nearly 360° at 1 AU. Energetic particles arrive at the spacecraft strongly delayed with respect to the first type III burst onset, which suggests the particles are not directly streaming away from an extended region but undergo strong scattering in the interplanetary medium. Different model scenarios have been investigated supporting the idea of perpendicular particle transport by diffusion. Further analysis and data of more events with large separation angles between SOHO and the two STEREO spacecraft are needed to investigate the ratio of perpendicular to parallel diffusion, which can vary significantly between different solar events.

2.6 Particle acceleration in interplanetary shocks. Particle events associated with CMEs can reach maximum intensity at the time when the shock passes the observer. Historically, these are called Energetic Storm Particles (SEPs) and are usually accelerated in strong fast forward shocks. Based on ERNE observations during solar cycle 23, it was found that the high-energy ESP-effectiveness of fast forward shocks had a solar cycle dependence. Continuation of ERNE measurements will allow extending these investigations to cover solar cycle 24 and take advantage of multi-point measurements by combining *SOHO* and STEREO observations.

2.7 Solar energetic particle storm forecasting. COSTEP measurements of relativistic (150 keV - 10 MeV) electrons are routinely used to forecast SEP events, and this information is utilized by, among others, the Space Radiation Analysis Group (SRAG), which advises ISS operations in Houston. The electrons act as test particles by probing the continuously changing heliospheric transport conditions in the same region of the heliosphere through which the slower-moving protons have to propagate. This is a unique capability, as the electron energy ranges measured by COSTEP are not accessible to other, existing spacecraft instrumentation in the inner heliosphere.

Goal 3: Continue to offer robust solar wind proton and EUV irradiance measurements (H1, H3, J3)

As noted above, the Mass Time-of-Flight (MTOF) instrumentation in the European-led CELIAS investigation is a NASA-funded effort (at the University of Maryland). The MTOF team also processes, in near-realtime, proton monitor measurements of solar wind speed, density, thermal speed, and north-south deflection angle that are far more robust during intense SEP events than similar measurements onboard ACE. The MTOF proton monitor data benefit from *SOHO*'s > 9.5 hours per day of realtime contact, far more than WIND's few short contacts per week. In addition, the Maryland team continues to reformat and calibrate the CELIAS Solar EUV Monitor (SEM) broad-band EUV flux measurements, which continue to be helpful in tracking throughput changes in SDO EVE.

As noted in Section III, we envision being able to continue CELIAS MTOF measurements through part of FY14, but no farther without funding beyond that in the current budget guidelines.

III. Technical and Budget, FY14 - FY18

IIIa. The automation of SOHO operations

Starting in late 2006, in response to the budget guidelines from a previous Senior Review, the *SOHO* Flight Operations Team (FOT) began an in-house reengineering effort to automate *SOHO* mission operations. In the first phase of the transition from well-manned coverage of all contacts to complete automation with Observatory Engineers (OE's) on call, in 2007 September the FOT began the routine automation of all GSFC-local nighttime contacts. That followed three months of engineering trials when almost all night contacts were automated. All contacts were automated by the end of FY2009. Anomaly resolution and a restricted subset of critical spacecraft operations will continue to be carried out by the FOT; otherwise, pass plans are constructed in advance that contain all command procedures and loads. The automation software directs the commands to the existing TPOCC software, and COTS anomaly detection and notification software notifies the OE's and appropriate experiment team members (in case of an instrument anomaly).

In 2010, the EOF Core System (ECS) was ported to a more sustainable platform, as was the authentication server used to authorize remote instrument commanding. Diverting funds that would otherwise have been used for science to those tasks was driven by NASA requirements for IT security: operating systems must be patchable to meet any newly emerged vulnerability, so legacy systems are not allowed. Further work of this kind that is required by both system age and security requirements is discussed in Section IIIf, below.

Daily roll steering law updates to keep the *SOHO* spacecraft Z axis aligned with the solar rotation axis were discontinued after the end of MDI science operations in 2011 April. Instead, the spacecraft is allowed to maintain its natural orientation with respect to the ecliptic. (Maintaining the spacecraft Z-axis with constant orientation with respect to the solar rotation axis was an MDI requirement; without that maintenance, LASCO images can be rectified on the ground.) Instead of the ~ 22 WYE in the early years of *SOHO*, these changes have allowed shrinking mission ops support to < 4.5 FTE of flight operations team, 0.6 FTE of Flight Dynamics support, 0.8 FTE of system administration support, and 0.67 FTE of DSN scheduling. An additional ~ 2 FTE provide administrative, data collection, and software development support.

IIIb. Risk mitigation in a fully automated scenario

We would be remiss if we did not discuss the risks we assumed in the transition to automation. Foremost among these are the possibility of inadequate notice of a critical anomaly, and failure to be able to act in time to correct a mission-threatening situation in a timely fashion. The COTS monitoring and notification software provides for full and timely FOT insight into the nature and seriousness of the anomaly. Timeliness of notification is clearly important, but seventeen years of *SOHO* operations have taught us that we never want to respond too quickly to a spacecraft anomaly; indeed, experience has shown that a series of meetings of program management, operations teams, and engineers beginning the next working day is always adequate to insure both the efficient use of onboard resources and fastest *safe* recovery of science operations, rather than a rushed "solution" that simply generates further anomalies. The Emergency Sun Reacquisition (ESR) mode into which the spacecraft falls in the case of serious anomalies is stable for up to 48 hours, and ground intervention at scheduled contacts (more frequent in the case of spacecraft anomalies) minimizes thruster fuel usage. With fewer instruments operational, full recovery is faster than during the earlier operations, despite less DSN contact. Both the experience of numerous missions operated by GSFC, including the ACE mission at L1, and the *SOHO* automation experience to date, demonstrate that anomaly rates actually decrease when operations are automated. Most importantly, the reduction in size of the FOT is counterbalanced by the expertise of the staff, which now consists primarily of veteran Observatory Engineers who are intimately familiar with the spacecraft and ground system.

IIIc. The SOHO to Bogart transition

In FY10, *SOHO* operations transitioned to the "Bogart" mission, so named to reflect our desire to "smoke" the "cigarette" of *SOHO* science and space weather situational awareness to its very end. UVCS, CDS, and (sometimes) SUMER were thereafter operated remotely, and MDI completed its intercalibration with HMI before suspending science operations. (MDI remains in working order, and could be reactivated if SDO HMI were to suffer a serious malfunction.) After a shorter period of intercalibration with SDO Advanced Imaging Array (AIA), EIT also stopped observing, except for two four-wavelength "synoptic sets" per day to monitor long-term detector changes.

At the beginning of FY11, the LASCO (prime), and MDI, CDS, and SUMER workstations and the EOF Core System (ECS) were moved to Building 21 at GSFC, which houses the Heliophysics Division, and the *SOHO* EOF was abandoned. The Mission Operations Center (MOC) and a facility for the non-resident PI teams' workstations, including those of UVCS, remained in former current location in Bldg. 3, along with workstations for COSTEP, GOLF, and VIRGO.

IIId. Further contraction

We expect the end of SUMER science operations before the end of CY2013, after a campaign of intercalibration and co-observing between SUMER and the IRIS SMEX mission. The CDS PI also expects to cease science operation in the spring of 2014, as a result of funding changes in the parent country.

IIIe. Science team funding

With the exception of CELIAS (a foreign PI-led effort with a lead US Co-I) and UVCS, whose operations were partially funded by the home institution (SAO) in FY11 - FY13, funding for US science teams was phased out after FY10. UVCS science operations ended on 2013 January 23, and final archiving and documentation of the UVCS data will be completed with FY12 funds. There are sufficient funds in FY14 to continue to operate CELIAS for at least part of the year, and then to complete their archiving as well. LASCO is operated by 1.6 FTE of skilled operators of the instrument who have worked under contract directly to NASA and under the direction of the Project Scientist for several years, and will continue to do so in the proposed extensions. The operators will also be responsible for the maintenance and administration of the ECS, which enables secure, near-realtime commanding between both local and remote science teams' workstations and the *SOHO* Command Management System (CMS) on the Restricted IONet. As part of the planning for the Bogart mission, we examined whether the ECS and CMS were necessary, and concluded that they were: the FOT uses the CMS to build command loads, and we need a secure gateway between the investigators' workstations and the CMS. The LASCO PI team engineering expertise will continue to be available, on call, if instrument anomalies occur.

Thus, ***no US PI teams are funded for science analysis activities, or have been since FY10***. Although the remaining European PI teams will continue to operate their instruments at no additional cost to NASA, *the primary NASA interest in SOHO remains one of providing an essential space weather resource with a unique vantage point*.

IIIf. Budget

The SOHO budget guideline for FY14 is adequate, but then steps down by ~15%. The budget guidelines for FY15 and beyond (see Table III-2) are insufficient for a reasonable degree of risk management. Aside from the project scientist and resource analyst (unfortunately required by NASA), the only cost elements in the *SOHO* budget from FY15 on are mission operations and the operation of the LASCO coronagraphs.

SOHO mission operations have been reduced by over 75% (in uninflated dollars; more like 90% using the CPI change from 1995 to 2013). There really is nothing left to remove that would not increase the risk to a unique and critical national capability to an unreasonable degree. We have four observatory engineers (one of whom manages the team), a ground system manager, and a DSN scheduler, as well as a part-time scheduler at JPL. The rest of the contractor team work year equivalents (WYEs) are in system administration (increased over previous years because of an increasing load of NASA IT security requirements) and software engineering (sustainability/reengineering).

Sustainability Activity	FY14	FY15	FY16	FY17	FY18
Complete TPOCC and CMS port (begun in FY13)	45				
SLE multi-user and port	137				
SOHO simulator port	149	271	3		
Total	331	271	3		

*Table III-1. Additional funds needed in FY14 - FY18 for required platform sustainability software efforts, FY14 - FY18. All figures in $K. Note that these figures are **not** included in the budget spreadsheet (Table III-1).*

The actual situation is in fact worse, since despite the reengineering of the ECS and DPS to more sustainable and lower-cost platforms, we still need to port the Transportable Payload Operations

Control Center (TPOCC) code, the Command Management System (CMS) that both provides secure connections for instrument team commanding and makes possible FOT upload of commands to the spacecraft, and the *SOHO* spacecraft simulator to sustainable platforms, simply to be in compliance with NASA IT security requirements for operating system patchability. We also need to validate that our current Space Link Extension (SLE) software used for telemetry acquisition from DSN is compatible with the new version to which DSN is transitioning. If sufficient funds were available in the out years, we would seek additional funds as noted in Table III-1.

The simulator port is not included in the nominal budget table even though a high-fidelity software simulator was cited as a requirement in the report of the ESA/NASA joint incident investigation board after the 1998 loss, and subsequent recovery, of *SOHO*.

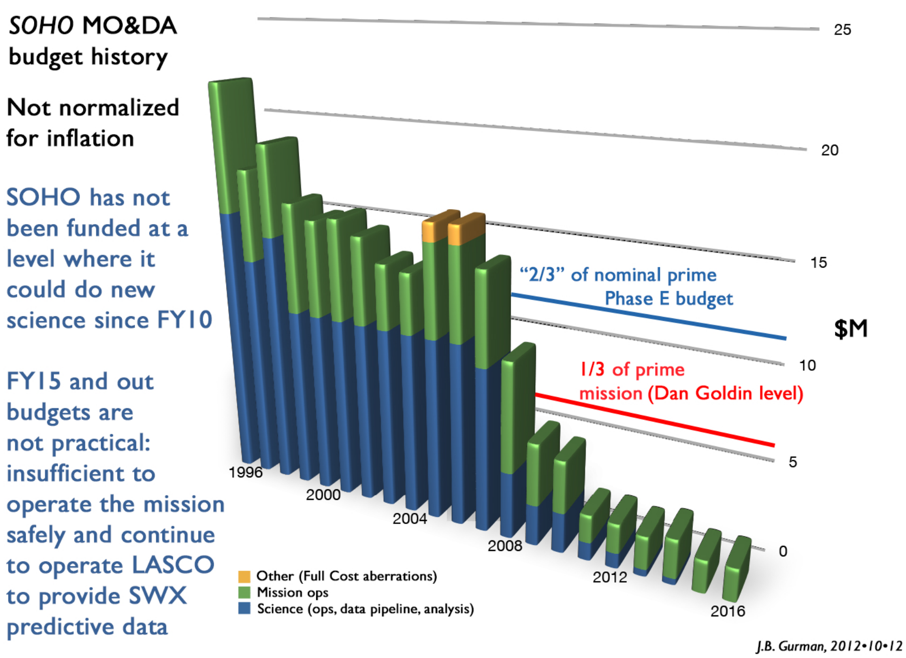


Figure III-1. SOHO budget history since the beginning of prime Phase E, with no inflation taken into account. FY14 and beyond contain no funding for scientific analysis. Assuming that the FY98 level of funding represented prime Phase E, FY15 - FY18 represent an order of magnitude lower funding.

Finally, we note by way of Figure III-1 that *SOHO* has not enjoyed funding in the range of 2/3 of prime Phase E since FY2007, nor 1/3 (the level originally mandated for mission extensions in the initial Sun-Earth Connections senior review in 1997) since FY2010. That is only appropriate, given the reduction in the scientific scope of the NASA-funded investigations, but it should also make it clear that serious savings have been accomplished in mission operations, even as the spacecraft and ground system have aged. Mission and LASCO operations are not free, however, and we hope the review panel will agree that the current FY15 and beyond funding levels are inadequate for safe operations, and recommend a budget more in line with the FY14 figure.

Project Name: SOHO						
I. FY14 - FY18 NASA Full-cost Guidelines:						
		FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
	Total	2,189.0	1,873.0	1,898.0	1,904.0	1,904.0
II. FY14 - FY18 '5-way' Functional Breakdown:						
		FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
	1. Development	0.0	0.0	0.0	0.0	0.0
	2.a Space Communications Services	13.6	13.6	13.6	13.6	13.6
	2.b Mission Services	1,530.8	1,573.9	1,616.2	1,659.7	1,655.9
	2.c Other Mission Operations	0.0	0.0	0.0	0.0	0.0
	3. Science Operations Functions	644.6	516.6	526.8	541.7	550.5
	4.a Science Data Analysis	0.0	0.0	0.0	0.0	0.0
	4.b Guest Observer Funding	0.0	0.0	0.0	0.0	0.0
	5. E/PO	0.0	0.0	0.0	0.0	0.0
	Total*	2,189.0	2,104.1	2,156.6	2,215.0	2,220.0
	Overguide		-231.1	-258.6	-311.0	-316.0
IIa. FY14 - FY18 Labor breakdown:		FTEs/WYEs	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs
	1. Mission Operations	9.1	9.1	9.1	9.1	9.1
	1.a CS Labor]	0.2	0.2	0.2	0.2	0.2
	1.b WYE (Contractor) Labor	8.9	8.9	8.9	8.9	8.9
	2. Science Operations and Data Analy:	3.2	2.1	2.1	2.1	2.1
	2.a CS Labor	0.5	0.5	0.5	0.5	0.5
	2.b WYE (Contractor) Labor	2.7	1.6	1.6	1.6	1.6
III. FY14 - FY18 Instrument team breakdown						
		FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
	1. LASCO-GSFC	341.0	354.5	362.5	376.4	384.8
	2. LASCO-NRL	50.0	50.0	50.0	50.0	50.0
	3. Project science	109.5	112.0	114.3	115.3	115.7
	4. CELIAS (Umd)	148.1	0.0	0.0	0.0	0.0
	Other science teams	0.0	0.0	0.0	0.0	0.0
	Other mission expenses	1,544.4	1,587.5	1,629.8	1,673.3	1,669.5
	Total**	2,193.0	2,104.1	2,156.6	2,215.0	2,220.0
	**Totals for Table III should be identical to totals in Table I.					
IV. FY14 - FY18 '5-way' Breakdown for in-Kind contributions:						
		FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
	1. Development	0.0	0.0	0.0	0.0	0.0
	2.a Space Communications Services	26,847.0	27,652.4	28,482.0	29,308.0	30,187.2
	2.b Mission Services	560.2	577.0	594.3	612.1	630.5
	2.c Other Mission Operations	0.0	0.0	0.0	0.0	0.0
	3. Science Operations Functions	0.0	0.0	0.0	0.0	0.0
	4.a Science Data Analysis	0.0	0.0	0.0	0.0	0.0
	4.b Guest Investigator Funding	0.0	0.0	0.0	0.0	0.0
	Total	27,407.2	28,229.4	29,076.3	29,920.1	30,817.7

Table III-2. SOHO budget for FY14 - FY18. There is no way to operate the mission at a sensible level of risk at the budget levels prescribed for FY15 and later.

Appendix A. Education and Public Outreach

Education

SOHO educational activities in the past were generally been carried out by the two US PI teams at major universities (MDI at Stanford and UVCS at the Harvard-Smithsonian Center for Astrophysics). Stanford's MDI budget ended with FY10, and UVCS operations were extended past FY10 only by limiting the budget strictly to operations, and then only with the donation of fractional FTE's from the Smithsonian Institution. Thus, no formal educational activities are proposed for the remainder of the *SOHO* mission.

Outreach

Given the dramatic new imaging and video coming from *Hinode*, STEREO, and particularly SDO, it is only appropriate for *SOHO* to take a back seat in outreach. *SOHO*'s visual outreach materials have been clearly eclipsed by the awesome potential of SDO for communicating the drama of the solar atmosphere – except for dramatic observations by the LASCO coronagraphs. We will continue to run *SOHO* "Hot Shot" stories when scientific news breaks, usually in conjunction with NASA and/or ESA press releases, and roughly every other week, the "Pick of the Week" media developed for the American Museum of Natural History and the Museum Alliance focuses on LASCO observations (in alternation with STEREO results). Those efforts are carried out by Steele Hill, the veteran Heliophysics media specialist at GSFC who started as the *SOHO* media expert. We will continue to fulfill every request from the media for *SOHO* content and scientific comment, but it is simply more appropriate for the newer solar and heliospheric missions to grab the spotlight that *SOHO* and TRACE nearly monopolized for twelve years before the launch of SDO. Since outreach activities will be driven primarily by other missions in the years covered by this proposal, we assume that they will continue at the ~ $20K/year level for Mr. Hill's time – but only if the *SOHO* budget is increased to cover basic mission and LASCO operations in FY15 - FY18.

Despite striking imagery from *Hinode* and STEREO, interest in the *SOHO* Website remains high, with over 285 Tbyte of traffic generated by over 200 million page views in each of the last two years (2011 and 2012) – a mean rate of over 72 Mbps. As a result of the SDAC/*SOHO*/STEREO SSC moving to a 2 Gbps connection to the Internet, we have been able to move the traffic back to the Goddard from our European mirror site.

Public interest in SOHO (as measured by Internet traffic) has constantly increased over time. The SOHO web servers operated by at GSFC now serve an average of 60 million requests and over 25 TB of data each month (twice the data volume of two years ago). Since launch, the SOHO servers have served over 1 PByte of images and data in response to over 4 billion page requests. Time-lapse movies of LASCO images during the active period at the end of January and early March 2012 as well as during the fly-by of comet Lovejoy in the middle of 2011 December proved so popular that there was interference with mission network traffic flow at GSFC (daily averages > 2 TB of downloads, i.e. daily average data rates of more than 180 Mbit/s).

Appendix B. Mission Archive Plan

With some minor exceptions, *SOHO* active archiving is robust: level-0 or -0.5 data are publicly available within minutes to hours of their ground receipt, level-1 and higher products within a few months to a year, and documentation and calibration databases are also publicly available. The existence of multiple copies of the archive with public Internet access insures the survival of the current state of the archive, and facilities in both Europe and the US used for active archiving will serve as resident archives after the mission ends. Instrument resource Web pages direct potential users to publications, calibration information, software descriptions, and user's guides, as well as to a variety of methods for accessing the data. All *SOHO* data are accessible via the Virtual Solar Observatory.

Existing Mission Archives and Online Resources. The information on the SOHO mission, instruments, spacecraft ephemeris, attitude, the access to both the SOHO mission archive (less MDI helioseismology observations), and publications databases, as well as access to calibration and data analysis software is available both in the US (NASA/GSFC), and in Europe (ESA/ESAC). There are two Websites and two mission archives, providing independent, redundant access points, and disaster recovery for each other, one in the US and one in Europe. Each SOHO instrument PI team has a Webpage with links to standardized resources, including, but not necessarily limited to: published articles in the refereed literature describing the instrument; initial results; operational constraints; data file format description; metadata; reformatting levels; algorithms for reading the data files; recommended data access and analysis software; software and databases for calibrating lower-level data products; a user's guide to the instrument and data; and PI team contact information. Links to all of these instrument resources pages can be found at the *SOHO* instrument resources page. The MDI helioseismology observations, together with the relevant documentation and software, are available online at the Solar Oscillations Investigation Website. All SOHO remote-sensing data, including those at Stanford, are also accessible via the Virtual Solar Observatory (VSO), through any of the multiple access methods (physical observable, data source, data provider, etc) offered by the VSO.

Available data products.

Final science data products by instrument. Files are in FITS format except where indicated. Direct access to either of the two science SOHO archives is available online.

GOLF

- Uncalibrated, full time resolution data per photomultiplier channel, level-1.
- Calibrated, full time resolution data (whole Sun average Doppler velocity in m/s calibrated using three different methods) for the time period1996/04/11 - 2008/12/31.

VIRGO

- Level 1 high resolution data organized per detector.
- Correction tables to get from level-1 to level-2 TSI data.
- 1 hour cadence time series of calibrated total solar irradiance, PMO6V and DIARAD corrected (ASCII).
- 1 day cadence time series of calibrated total solar irradiance, PMO6V and DIARAD corrected, with DIARAD IRMB level 2 data (ASCII).

MDI

- Original telemetry as received by the SSSC (SFDU)
- Level-0 MDI image data, organized by Data Product Code (DPC), the onboard-generated data tags describing unique instrument configuration and observing sequence (709 different possibilities).
- Level-1.0 data which is calibrated data in units of m/s, gauss, etc., stored in datasets of (usually) hourly data organized by DPC. (759 distinct Level-1 data series).
- Level 1.4/1.5 data which are collected into datasets named by observables, which may have contributions from multiple DPCs. The 1.4 data are in telemetry order of cropped images, while the 1.5 data are

two-dimensional image arrays, reformatted from level 1.4 data if necessary. The 1.5 and higher data do not require special tables to use. There are 40 Level-1.4 series and 103 level-1.5.

- Level 1.7/1.8 data which are "recalibrated," best available data created on demand from the Level-1.4/1.5 data. Level-1.8 data is the lowest processing level that is recommended for use for most science data analysis, and include the latest information on image scale, image center position, magnetic zero level, &c. Level 1.7/1.8 data are usually recalibrated on the fly at time of export. Final recalibrated values will be used when the data are ingested into a resident archive.
- Level-2 data result from further standard processing for particular purposes. These data include products such as tracked data cubes of time-series of e.g. 15-degree regions in heliographic coordinates followed for 1664 minutes. These data are used for input to "timedistance" and "ring" local helioseismology analysis. There are 462 Level-2 products.
- SHT data, Spherical Harmonic Transform data: projections of Dopplergrams onto spherical harmonics. They are used for global helioseismology. There are 45 types, with varying ranges of mode degree-*l*.
- LOI 12 pixel images filtered with a 2 day triangular filter (in ASCII format).

SUMER

- Uncalibrated solar spectra organized by study
- Calibration files, software, and documentation

CDS

- Uncalibrated solar spectra organized by raster
- Calibration files, software, and documentation

EIT

- Uncalibrated, full-disk (and a small number of subfield) images in 171, 195, 284, or 304 Å
- Flat fielding, degridding, calibration files, software, and documentation

UVCS

- Uncalibrated UV spectra organized per XDL detector (each file holds multiple individual exposures)
- Uncalibrated visible light data (counts from the photomultiplier tube)
- Fully calibrated UV spectral and spatial maps, organized per XDL detector, through 2005/12/31
- Calibration files, calibration software, and documentation

LASCO

- Uncalibrated Fe XIV and other forbidden line C1 inner coronal images (1996 - 1998); "level 0.5"
- Uncalibrated white light, 1024x1024, coronal images grouped per coronagraph (C2 and C3); "level 0.5"
- 1024x1024 resolution white light coronal images calibrated to mean solar brightness, grouped per detector (C2 and C3) through 05/04/2005; "level 1"

CELIAS (all files in CDF except where indicated)

- CTOF sensor rates: Start rate, Double Coincident rate, Triple Coincident rate, Solar wind speed, Proton rate, Helium rate (rates in Hz), all until the power supply failure of CTOF on 17 August 1996.
- CTOF matrix elements CDF CTOF high resolution matrix rates, including velocity of solar wind in m/s, all until the power supply failure of CTOF on 17 August 1996.
- CTOF pulse height analyzer (raw energy spectra), all until the power supply failure of CTOF on 17 August 1996.
- HSTOF matrix elements and high resolution matrix rates.
- MTOF sensor rates (Front SEDA rate, neutral stop rate, ion stop rate, neutral double coincidence, ion double coincidence, ion start rate, multiple front SEDA rate, multiple double coincidence rate, neutral rates).
- MTOF pulse height analyzer: Neutral/Ion identification, amplitudes, time of flight.
- MTOF time of flight spectrum (far and near sides of MCP).
- STOF high basic rate (including both STOF and HSTOF rates).
- STOF low basic rate (including both STOF and HSTOF rates).
- STOF matrix elements and high resolution matrix rates.
- STOF pulse height analyzer (raw energy spectra).

- PM radial spectra: solar wind speed and alpha (counts per 100 seconds).
- PM theta array (counts per 100 seconds) and total rates (Hz for each step).
- PM radial-theta array (counts per 10 minutes).
- SEM (photon counts).
- Proton Monitor 5 minute averages (p speed, density, thermal speed, arrival direction, predicted He speed (ASCII format).
- Solar wind speed (for O, Si, Fe), and densities (O, O^{+6}, O^{+7}), until the power supply failure of CTOF on 17 August 1996.
- Fe freeze-in temperatures and mean charge states, until the power supply failure of CTOF on 17 August 1996.
- Fe densities by charge state (from Fe^{+7} to Fe^{+16}), until the power supply failure of CTOF on 17 August 1996.
- Si densities (for Si^{+7}, Si^{+8}, Si^{+9}) until the power supply failure of CTOF on 17 August 1996.
- S^{+7} density, until the power supply failure of CTOF on 17 August 1996.

COSTEP (all files in ASCII format)
- Proton, deuterium, ^3He, ^4He:
    - 1 minute EPHIN counting rates given as intensities (in 1/cm^2/s/sr/MeV or 1/cm^2/s/sr/MeV/nucleon; 3 energy bands).
    - 1 minute EPHIN pulse height analysis (energy deposits in MeV).
    - 1 minute EPHIN rate correction (in counts).
- Proton, He: 15 second LION counting rates given as intensities (in 1/cm^2/s/sr/MeV) in 3 energy bands for protons, 1 for He).

ERNE (all files in ASCII format)
- LED onboard analyzed counting rates (proton and He intensities 1/cm^2/s/sr/MeV, 10 energy bands).
- HED onboard analyzed counting rate (proton and He intensities 1/cm^2/s/sr/MeV, 10 energy bands).
- LED and HED pulse height data (MeV).

SWAN
- Uncalibrated full sky Ly α synoptic maps in ecliptic coordinates (one every three days: full time resolution).
- Uncalibrated data organized per target of opportunity.
- Calibration files, software, and documentation.

All science data for all instruments except for MDI are available from the *SOHO* mission archives at GSFC and ESAC.

In addition, the following MDI science data products are served by the *SOHO* archive:
- Calibrated full solar disk 1024x1024 resolution 96 minute cadence average magnetograms (Gauss).
- Full solar disk 1024x1024 resolution 6 hour continuum images in arbitrary intensity units.

Also, the complete set of science data products is available through the Virtual Solar Observatory.

Up to date information about the time ranges for which the science data products are available in the SOHO archive can be found on the archive Webpage.

Browse products. SOHO browse products are accessible at the *SOHO* Website. These include full solar disk 'near real time' images from EIT (171, 195, 284, and 304 Å), MDI (magnetograms and visible continuum) until 2011/1/11 (then replaced by corresponding SDO/HMI products) and LASCO (visible light C2 and C3 coronagraph images). The URL above also provides access to a wide variety of browse products at PI facilities like Sun far side imaging, proton and energetic particle monitors, recent solar activity information and solar and heliospheric forecasting.

Mission data products. Available online from the *SOHO* ancillary data products Webpage, these products, including documentation of their contents, are: spacecraft attitude and orbit information are available in FITS and ASCII format; Time Correlation Log (onboard clock history) in ASCII; Daily Report (from Flight Operations Team) in ASCII; Command History Report in ASCII; Spacecraft Mode files in ASCII; and spacecraft monthly trending reports, including spacecraft events (in digital format but currently without public links).

Additional science data products to be included in the final archive

- GOLF mission-long calibrated data set of global velocity oscillations (in m/s).
- VIRGO level-2 data which include corrections for degradation , including: 1-minute data of VIRGO total solar irradiance (TSI), hourly data of TSI (with records on VIRGO agreed, PMO6V and DIARAD corrected, PMO6V and DIARAD level 1.8); daily data of TSI (with records on VIRGO agreed, PMO6V and DIARAD corrected, PMO6V and DIARAD level 1.8); 1-minute, hourly and daily values of the 3 SPM channels; and SPM and LOI 1-min helioseismic data.
- SUMER level-1 calibrated FITS files (decompressed, reversed, geometrically corrected, flat-fielded).
- CDS/NIS level-1 calibrated FITS files.
- EIT level-1 calibrated FITS files .
- LASCO 1024x1024 resolution photometrically calibrated white light coronal images, grouped per detector (C2 and C3) for whole mission; "level 1"
- UVCS: Fully calibrated UV spectral and spatial maps, organized per XDL detector at least through end of 2008 when the detector developed address errors which require excessive human intervention
- ERNE additional data sets: new file types will be added containing LED and HED heavy particle spectra for selected periods and elements; and a new file type will be added containing HED anisotropy observations in a form of a single anisotropy index, describing the strength of the observed anisotropy, supplemented with pitch angle distributions from selected periods.

Available instrument software and documentation

All software specific to instrument teams is available from the Instrument Resource Pages on the SOHO Website, which follow a common format for all instruments. These at least include: Instrument/hardware description; data file descriptions for science and calibration files; suggested method for reading data; data sources; calibration software, data analysis software, reference library (User Guide, Software Notes, Software Resources), and contact information.

Some of the instrument resource pages listed above describe software that can be used with their data; most of the other remote sensing instruments have extensive SolarSoft code libraries for data reduction and analysis (cf. the SolarSoft "soho" tree). The contents of the SOHO branch of the SolarSoft tree is available online. It should be noted that considerable parts of the SolarSoft tree for each instrument are used to "prep" (e.g. flat-field, degrid, rectify, and/or calibrate) the raw data stored in most of the current FITS files. When the fully calibrated and corrected files are available along with the level-0 data in the final archive, the various <instrument>_PREP routines will be useful only for testing alternate calibration approaches. The entire point of widely adopted, standard formats such as FITS is to allow calibrated data to be used with anyone's software, so long as it incorporates a FITS reader. In principle, CDF should allow the same facility. In practice, such generalization is only possible with good metadata; the SOHO FITS files use a standard set of keywords agreed on before launch that still form the basis for similar standards for the VSO, the STEREO mission...

Transition to Resident Archives

Data Access. Data will continue to be served via both mission archives in the US and in Europe, and the Virtual Solar Observatory (VSO). We will work with the Virtual Heliospheric Observatory to enable their service of as many heliospheric data sets directly as possible; in any case, all the SOHO data will be available via the VSO through translation of SPASE-based queries to VSO-native queries.

The entire MDI data collection of about 220TB has now been migrated into the Solar Dynamics Observatory (SDO) Helioseismic and Magnetic Imager (HMI) and Atmospheric Imaging Array (AIA) Joint Science Operations Center (JSOC) Science Data Processing (SDP) activity. There are about 43,000 distinct MDI Data Storage and Distribution System series names mapping into the same number of JSOC series. Also, a proposal for virtual observatory support was selected and funded: In 2013, MDI moved dataseries into the JSOC DRMS with per-image record access with full metadata support instead of the base per-dataset access.

Metadata. Most of the SOHO remote sensing data are stored in FITS files which have extensive metadata available in their headers; it is in part upon those metadata that the VSO has based its data dictionary.The translation between SPASE and the VSO data model is an ongoing effort of the "Heliophysics Virtual Great Observatory," the consortium of virtual observatory efforts funded by the Heliophysics MO&DA program.

Long term archiving

Europe. An ESA *SOHO* long term mission archive has been deployed at the European Science Astronomy Centre (ESAC), the site which is ESA's focal point for science operations and data archiving for the missions of ESA's Science Programme. The new archive is based on the technical infrastructure already developed by the ESAC Science Archive Team for astronomy and planetary missions, and has the capability of interfacing with the virtual observatories being deployed around the world. The science archives at ESAC are the permanent holding places for ESA's scientific data, including SOHO's, and they are, therefore, long term archives which hold their data in excess of 10 years.

US. The Heliophysics Science Data Management Policy calls for transitioning mission archives from Resident Archives to "Final Archives" (not to be confused with long-term archival) when it is no longer cost effective to retain the data in the Resident Archives and names the Solar Data Analysis Center (SDAC) as one of those Final Archives. We therefore expect that the *SOHO* archive will continue to be served by the SDAC for some years after the end of the mission, while a backup copy of all data, documentation, and software is deposited in a deep archive facility to be determined in consultation with NASA Heliophysics management.

Appendix C. SOHO publication record, 2010 - 2012

SOHO ***refereed*** publication rates through the first few weeks of calendar year 2013 can be found in Table A-1.

Calendar Year	Refereed Journals only
1996	31
1997	125
1998	174
1999	297
2000	295
2001	210
2002	289
2003	305
2004	332
2005	330
2006	272
2007	360
2008	320
2009	321
2010	275
2011	297
2012	240
2013 (to February 28)	39
Total	4505

Table C-1. SOHO refereed papers

Here, a "*SOHO* paper" is taken to mean any paper using *SOHO* data, or concerning models or theoretical interpretations of *SOHO* measurements.

"Market share" In the years since the launch of *SOHO*, there have been over 3,800 different authors and co-authors of *SOHO* papers in refereed journals. Since *SOHO* carries both *in situ* and remote sensing instruments, there is a large potential pool of authors. Considering just the remote sensing instruments, there are roughly 600 members of the AAS Solar Physics Division and a roughly equal number of active solar physicists in Europe and Asia (combined). Past experience indicates that approximately 75% of those are "active," in the sense of publishing at least one refereed paper per year, so *SOHO* is clearly serving a large number of members of the heliospheric community as well.

In the years 2010 - 2012, nine Ph.D. degrees were awarded for theses involving *SOHO* data (two from Stanford University, the remainder abroad). There may well be others that have not been captured in our database.

Publication rate. Despite drastically reduced funding for scientific analysis of *SOHO* data both in the US and the countries of the European Principal Investigators over the last several years, the *SOHO* publication rate has remained healthy. Full-disk magnetograms and imagery from *SOHO* MDI and EIT, as well as the earth-Sun line coronagraphy from LASCO made *SOHO* a source of unique data until SDO began observing regularly in the spring of 2010 – and in the case of LASCO, for the foreseeable future. Even though the ESA formation-flying testbed PROBA-3, after at least two delays, is currently scheduled for launch in 2017, its baseline plan includes only partial ground contact each day. NOAA and other US government agency plans for space coronagraphs also remain just that – plans. ***LASCO remains the only visible-light, earth-Sun line coronagraph on any mission currently in operation or confirmed for fiscal years 2014 - 2018 with complete (realtime and playback) coverage.***

We are convinced that this success is based on the open and convenient accessibility of *SOHO* data and analysis software. Only a data policy of this type is likely to draw in the widest possible scientific community — including amateurs — to the enterprise of mining Heliophysics System Observatory data for their maximum scientific return.

Bibliography. Lists of *SOHO* publications in refereed journals in 2010, 2011, and 2012 are available online at: http://umbra.nascom.nasa.gov/soho/sr13/publications/ or at *via* the links to each calendar year.

Appendix D. Spacecraft and Instrument Status, 2013 March 1

Spacecraft

- All spacecraft subsystems that survived the offpointing of 1998 are still operational, except for the east-west High Gain Antenna (HGA) gimbal mechanism, and the fine and coarse sun-pointing anomaly detectors
- The solar arrays, with two of the eight sets of sub-arrays shunted, still supply 77.58% of at-launch power, with adequate margin for all loads
- 113 kg of hydrazine remains in the tank, sufficient for several hundreds of years of maneuvers

GOLF

- Operating nominally, with data continuity ~98% outside *SOHO* 1998-1999 "vacation" periods, including no losses during telemetry "keyholes"
- Overall throughput down by a factor of <7 since launch, but:
  - largest noise source is the Sun itself, so negligible adverse effect over most of the frequency range, including that in which the *g*-modes are expected
  - significant reduction in signal to total noise ratio in a region around 1 mHz
- No reason to doubt that GOLF can continue to function in its present mode for several years
  - Complete redundant channel still available, though unused since initial, on-orbit commissioning

VIRGO

- All VIRGO instruments (the two types of radiometers: PMO6V and DIARAD, the filter radiometers SPM, and the luminosity oscillation imager LOI), are fully operational and performing properly. The degradation of the SPM red, green and blue channels has decreased the initial sensitivity to about 75, 26 and 8 %, respectively. The corresponding rates have changed from 220, 460 and 660 ppm/day in 1996 to 65, 75 and 40 ppm/day in 2009. The blue channel is therefore still sufficiently sensitive to provide reliable data with an instrumental signal-to-noise ratio of about 10 in the 5-minute range. The radiometers PMO6V and DIARAD show a total change of sensitivity of 4200 and 570 ppm, respectively. This can be accurately corrected with an uncertainty of less than 100 ppm over the past 13 years; hence the radiometry is also accurate enough to guarantee reliable TSI values into the future.

MDI

- Fully operable, but science operations ceased in 2011 April after intercalibration with SDO / HMI

SUMER

- Lost the KBr-coated section of the remaining detector. The performance of the bare section is still nominal; lines below 800 Å and 2nd order lines at longer nominal wavelengths can still be observed.
- Azimuth drive suffers step losses of 10 - 20%, with the result that raster scans cannot be reliably completed. Using encoder readings, positing is still possible with good accuracy, but only with ground interaction by an observer.
- Ground system: nominal.
- All remaining resources will be dedicated to an IRIS-SUMER campaign in the summer of 2013. Thereafter, the PI has no plans to operate the instrument.

CDS

- GIS nominal; no recalibration or changes to high voltages have been necessary in the past 3 years.
- NIS nominal; microchannel plate current anomaly in 2005 July appears to have been self-healed after a series of tests and is being used for regular observations again; sensitivity in short wavelength channel 40 - 80% of pre-launch levels; expect drop to no worse than 20 - 60% if CDS is operated throughout the Bogart mission
- Electronics nominal; trending shows no aging of components
- Mechanisms: All mechanisms continue to operate nominally. Mechanism lubrication carried out every 3 - 4 weeks.
- Thermal: As with all other components of *SOHO*, the sunward side of CDS shows a secular increase in temperature, but analysis of the science data shows that the NIS wavelength calibration remains within tolerances.
- Onboard software: No issues
- Ground systems: Migrated from GSFC to RAL in 2011 July.

EIT

- EIT is nominal
- Instrument throughput stable since 2005
  - Current 195 Å throughput comparable to that in mid-1999
  - CCE loss can be tracked accurately with calibration lamp images
  - Degradation now understood and modeled
  - Present exposure times range from 12 s (195 Å) to 2 m (284 Å): lots of latitude left

UVCS

- By late 2012, the UVCS detectors and mechanisms had degraded to the point where the PI determined it was no longer capable of making meaningful measurements, and decided to turn the instrument off.

LASCO

- Thernisien *et al.* (2005) have performed a detailed analysis of the intensity of a set of about 50 moderately bright stars that transited through the C3 field of view
  - These 50 stars generated about 5000 observations during the lower cadence in the first three years of *SOHO* operations and about 15000 observations thereafter
  - All stars have spectra well known from 13-color photometry
  - Using these stellar spectra as standards and the observed LASCO count rates, derived the photometric calibration factors of the C3 coronagraph for all five color filters with an absolute precision of ~7%
  - Decrease in the instrument sensitivity found to be only ~3.5% over the 8 years studied or < 0.5% per year
- C2 response changes similar
- The Fabry Pérot interferometer in the C1 coronagraph did not survive the extreme cold the instrument experienced (-80C) during the 1998 *SOHO* offpointing

CELIAS

- MTOF/PM, STOF/HSTOF, SEM nominal
  - MTOF, PM efficiency degradation of 2 (Fe) to 5 (H); still extremely high S/N
  - STOF performance stable, MC degradation compensated for by increase in HV
  - SEM exhibits a very slow rate of throughput degradation, consistent with a model established in 2000.
- CTOF impaired since 1996 October (HV power supply hardware failure)

COSTEP

COSTEP consists of two sensors, the Low-Energy Ion and Electron Instrument (LION), and the Electron, Proton, and Helium Instrument (EPHIN). Both instruments have suffered some degradation but continue to generate valuable scientific data and fulfill their scientific goals.

- LION: Unexpectedly high noise level in the LION detectors since shortly after launch have resulted in the loss of the lowest energy channels (< 80 keV). In the course of the mission, three of the four LION sensor heads developed disturbances, some of which can be mitigated by careful data analysis. The disturbed periods are well documented in the level-2 data specification document. As of 2009 December one LION sensor head is still functioning nominally, one has a high background, one has a moderate background and is still useful during energetic particle events, and one is no longer functional.

- EPHIN: Detector E of the EPHIN instrument showed steadily increasing noise levels throughout 1996, and had to be switched off (on 1996 October 31) to guarantee reliable measurements with the instrument. By changing the instrument configuration, the EPHIN measurements can still be achieved with slightly degraded energy resolution in a limited energy range (3-10 MeV for electrons and 25-41 MeV/n for ions). Since 2008 January, the front detector A has shown elevated noise levels correlated with heliocentric distance; this indicates that the secular heating of the front of the spacecraft has finally produced an effect after 12 years. No significant performance degradation is seen in this detector, however, and the scientific goals of EPHIN can still be achieved.

ERNE

- Secular increase in temperatures at front of spacecraft has caused increased detector leakage currents. Including radiation effects, the increase during the last five years has been roughly 20 $\%yr^{-1}$. The secular temperature increases have led to ERNE only being usable about ten months out of the year, since the electronics will switch off during perihelion.

- One of the detector channels of the topmost ERNE/HED detector layer malfunctioned on 2000 November 21. Updated onboard software accounts for this issue: the geometrical acceptance (view cone) of the detector is unaffected, as is the measurement of the heavy nuclei (Carbon and heavier). Also the light nuclei are unaffected up to an energy of ~ 20 MeV/n. Between 20 MeV/n and 120 MeV/n (maximum energy measured by ERNE), both the coordinate and energy values of the affected detector become increasingly unreliable. This, however, has no effect on particle identification and produces only marginal statistical fluctuation on the total energy of these particles that deposit most of their energies in the lower detector layers.

- One of the detector bias voltages of the nominal bias source failed in 2009 September. After switching to the redundant bias source, operations continued normally.

SWAN

- Instrument status unchanged since 2001
    - All subsystems functional, except for the hydrogen cells, which have lost their molecular H gas, most likely due to small leaks at the junction between the glass and the MgF_2 windows. The last H cell observations were performed in 2007.
    - Principal scientific objective, the study of the solar wind mass flux distribution, is not affected by the H cell status.

Appendix E. Research Focus Areas, NASA Heliophysics Roadmap, 2009 - 2030

Research Focus Areas

- **F1** Magnetic reconnection
- **F2** Particle acceleration and transport
- **F3** Ion-neutral interactions
- **F4** Creation and variability of magnetic dynamos

Open the Frontier to Space Environmental Prediction

The Sun, our solar system, and the universe consist primarily of plasma. Plasmas are more complex than solids, liquids, and gases because the motions of electrons and ions produce both electric and magnetic fields. The electric fields accelerate particles, sometimes to very high energies, and the magnetic fields guide their motions. This results in a rich set of interacting physical processes, including intricate exchanges with the neutral gas in planetary atmospheres.

Although physicists know the laws governing the interaction of electrically charged particles, the collective behavior of the plasma state leads to complex and often surprising physical phenomena. As the foundation for our long-term research program, we will develop a comprehensive scientific understanding of the fundamental physical processes that control our space environment.

The processes of interest occur in many locations, though with vastly different magnitudes of energy, size, and time. By quantitatively examining similar phenomena occurring in different regimes with a variety of techniques, we can identify the important controlling mechanisms and rigorously test our developing knowledge. Both remote sensing and in situ observations will be utilized to provide the complementary three-dimensional, large-scale perspective and the detailed small-scale microphysics view necessary to see the complete picture.

Research Focus Areas

- **H1** Causes and evolution of solar activity
- **H2** Earth's magnetosphere, ionosphere, and upper atmosphere
- **H3** Role of the Sun in driving change in the Earth's atmosphere
- **H4** Apply our knowledge to understand other regions

Understand the Nature of Our Home in Space

Humankind does not live in isolation; we are intimately coupled with the space environment through our technological needs, the solar system bodies we plan to explore, and ultimately the fate of our Earth itself. We regularly experience how variability in the near-Earth space environment affects the activities that underpin our society. We are living with a star.

We plan to better understand our place in the solar system by investigating the interaction of the space environment with the Earth and the effect of this interaction on humankind. We plan to characterize and develop a knowledge of the impact of the space environment on our planet, technology, and society. Our goal is to understand the web of linked physical processes connecting Earth with the space environment.

Even a casual scan of the solar system is sufficient to discover that habitability, particularly for humankind, requires a rare confluence of many factors. At least some of these factors, especially the role of magnetic fields in shielding planetary atmospheres, are subjects of immense interest to heliophysics. Lessons learned in the study of planetary environments can be applied to our home on Earth, and vise versa, the study of our own atmosphere supports the exploration of other planets.

Research Focus Areas

- **J1** Variability, extremes, and boundary conditions
- **J2** Capability to predict the origin, onset, and level of solar activity
- **J3** Capability to predict the propagation and evolution of solar disturbances
- **J4** Effects on and within planetary environments

Safeguard the Journey of Exploration

NASA's robotic spacecraft continue to explore the Earth's neighborhood and other targets in the heliosphere. Humans are expected once again to venture onto the surface of the Moon and one day onto the surface of Mars. This exploration brings challenges and hazards. We plan to help safeguard these space journeys by developing predictive and forecasting strategies for space environmental hazards.

This work will aid in the optimization of habitats, spacecraft, and instrumentation, and for planning mission operation scenarios, ultimately increasing mission productivity. We will analyze the complex influence of the Sun and the space environment, from origin to the destination, on critical conditions at and in the vicinity of human and robotic spacecraft. Collaborations between heliophysics scientists and those preparing for human and robotic exploration will be fostered through interdisciplinary research programs and the common use of NASA research assets in space.

Appendix F. Acronyms

ACE	Advanced Composition Explorer
AIA	Advanced Imaging Array (SDO)
CCMC	Coordinated Community Modeling Center
CDS	Coronal Diagnostic Spectrometer
CELIAS	Charge, Element, and Isotope Analysis System
CME	Coronal mass ejection
CMS	Command Management System
COSTEP	Comprehensive Suprathermal and Energetic Particle Analyzer
COTS	Commercial, off the shelf
CPI	Consumer Price Index
CPU	Central Processing Unit
CTOF	Charge Time-Of-Flight sensor of CELIAS
DIARAD	DIfferential Absolute RADiometer (active cavity radiometer) component of VIRGO
DSN	Deep Space Network
ECS	EOF Core System
EIT	Extreme ultraviolet Imaging Telescope
ENA	Energetic neutral atom
EPHIN	Electron, Proton, and Helium INstrument (part of COSTEP)
ERNE	Energetic and Relativistic Nuclei and Electron experiment
ESAC	European Space Astronomy Centre (ESA)
EOF	Experimenters' Operations Facility
ESA	European Space Agency
ESP	Energetic Storm Particles
ESR	Emergency Sun Reacquisition
EUV	Extreme ultraviolet
EVE	Extreme ultraviolet Variability Experiment (SDO)
FDF	Flight Dynamics Facility
FOT	Flight Operations Team
FTE	Full time equivalent (one person's work in one year)
FY	Fiscal year
GIS	Grazing Incidence Spectrograph of CDS
GOLF	Global Oscillations at Low Frequencies
GSFC	Goddard Space Flight Center
HED	High Energy Detector
HMI	Helioseismic and Magnetic Imager (SDO)
HSTOF	The flat deflection plate segment of the CELIAS STOF telescope
ICME	Interplanetary coronal mass ejection
IONet	Internet Operational Network (NASA)
ISS	International Space Station
L1	First Lagrangian libration point
LASCO	Large-Angle and Spectrometric Coronagraph
LED	Low Energy Detector
LOI	Luminosity Oscillations Imager component of VIRGO
MDI	Michelson Doppler Imager

MOC	Mission Operation Center
MTOF	Mass Time-of-Flight mass spectrometer of CELIAS
NIS	Normal Incidence Spectrograph of CDS
NOAA	National Oceanic and Atmospheric Administration
NSSDC	National Space Science Data Center
OE	Observatory Engineer
PM	Proton Monitor of CELIAS MTOF
PM06	Twin-cavity radiometer component of VIRGO
PMOD	Physikalisch-Meteorologisches Observatorium Davos
SAO	Smithsonian Astrophysical Observatory
SDO	Solar Dynamics Observatory
SEM	Solar EUV monitor of CELIAS
SEP	Solar Energetic Particle
SLE	Space Link Extension
SMEX	Small Explorer
SPM	Sun PhotoMeters (Spectral irradiance monitor component of VIRGO)
SRAG	Space Radiation Analysis Group
STEREO	Solar TErrestrial RElations Observatory
STOF	Suprathermal Time-of-Flight ion telescope, part of CELIAS
SUMER	Solar Ultraviolet Measurements of Emitted Radiation (UV spectrometer)
SWPC	Space Weather Prediction Center
TPOCC	Transportable Payload Operations Control Center
TRACE	TRansition Region And Coronal Explorer
TSI	Total Solar Irradiance
SWAN	Solar Wind Anisotropies
UV	UltraViolet
UVCS	Ultraviolet Coronagraph Spectrometer
VIRGO	Variability of Solar Irradiance and Gravity Oscillations
VSO	Virtual Solar Observatory
WYE	Work Year Equivalent (NASA term for an FTE of contractor time)
XDL	Cross Delay Line
XUV	Extreme UltraViolet (but shorter wavelengths than EUV)

Terms in blue are *SOHO* instruments.